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Abstract: Bears (Ursidae) have extensive home ranges and may move long distances, thereby potentially serving as hosts to, and vectors of, large numbers of ticks. We assessed the composition of the parasitizing tick community on American black bears (Ursus americanus) to discern hard tick species capable of successfully feeding, which is a necessary step for tick reproduction. We counted ticks from free-ranging, live-trapped, or road-killed black bears in southern Missouri, USA, during 2015, and collected a subset of engorged ticks (n = 967). All bears (n = 17) were infected with ticks (n = 6,993), with a mean intensity of 411 ticks/bear, of which 14% were engorged females. The infracommunity size of engorged ticks was 57 ticks/bear. From these engorged ticks, we identified 5 species: Amblyomma americanum, A. maculatum, Dermacentor variabilis, D. albipictus, and Ixodes scapularis. Amblyomma americanum was the most common species, collected on all surveyed bears, and represented 58.2% of engorged ticks, whereas D. albipictus and A. maculatum were the least common species, collected from only 3 and 4 bears, respectively, and representing 4.7% and 2.4% of engorged ticks, respectively. Our data suggest that individual black bears have the potential to host large numbers of ticks to engorgement, and may be important vectors for tick dispersal and for the maintenance of tick populations.

Key words: Amblyomma, American black bears, Dermacentor, Ixodes, Missouri, Ozark Highlands, parasites, ticks

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Ticks are obligate blood feeders that parasitize a wide variety of vertebrates and may act as vectors of numerous disease-causing microorganisms (Hoogstraal 1985, Oliver 1989, Jongejan and Uilenberg 2004). Hard ticks (i.e., Ixodidae) have a multi-stage life cycle with a blood meal required prior to molting (Kaufmann 2007). Furthermore, adult females require a blood meal for reproduction, and the quantity of the blood meal is correlated with the size of the egg mass (Koch and Dunn 1980, Lysyk 2014). Thus, an examination of blood-engorged adult female ticks on a host facilitates an assessment of the host’s contribution to future tick populations.

Mammals are primary hosts for adult Ixodidae. Although mammal species differ in their potential to successfully host ticks to the point of engorgement, in some cases larger bodied mammals may host greater numbers of ticks (Gallivan and Horak 1997). Further, large mammal species have more extensive home ranges and move greater distances than smaller mammal species (Mace and Harvey 1983), suggesting they have the potential to not only host increased numbers of ticks, but also to move these ticks farther than would smaller mammals. In this context, parasitism of bears (Ursidae) by ticks is potentially noteworthy because bears have some of the greatest home range sizes among terrestrial mammal species (Gompper and Gittleman 1991). Further, American black bears (Ursus americanus; hereafter, “black bear”), and male black bears in particular, have the potential for long dispersal distances (e.g., Stratman et al. 2001, Liley and Walker 2015). Given their size and movement potential, bears may play an important role in the ecology of ticks despite their relatively low population density compared with other mammal species.

To better understand the potential of bears to host Ixodidae to engorgement, we collected ticks from black
bears and examined the tick community parasitizing individual bears (the tick infracommunity) inhabiting the Ozark Highlands of southern Missouri, USA. Although the identity of ticks on black bears has been reported from several locales (Rogers 1975, Rogers and Rogers 1976, Manville 1978, Yamaha et al. 2009, Leydet and Liang 2013, Zolnik et al. 2013), detailed examinations of tick infracommunities of black bears have not been reported. We focused on two features of the tick infracommunity: species richness of the parasitizing tick community and intensity of parasitism by those adult female ticks able to remain on the host long enough to gain a blood meal.

**Study area**

We conducted this study in the Ozark Highlands ecological region (elevation = 70–540 m) of southern Missouri. This largely forested area contains predominantly oak (*Quercus* spp.), hickory (*Carya* spp.), and pine (*Pinus* spp.) species (Nigh and Schroeder 2002, Raeker et al. 2010). This ecological region has a mean daily minimum temperature (Jan) of −8°C to −4°C, mean daily maximum temperature (Jul) of 29°C to 32°C, mean annual precipitation of 102 to 132 cm, and mean annual snowfall of ≤46 cm (Nigh and Schroeder 2002, National Oceanic and Atmospheric Administration 2013).

**Methods**

We counted ticks from bears examined between June and August, 2015. Bears were chemically immobilized as part of another project (Hiller et al. 2015a, b) excepting one individual that was vehicle-killed. All capture and handling procedures were approved by the Mississippi State University Institutional Animal Care and Use committee (protocol 13-094). We collected all observed engorged ticks using fine forceps. We examined bears for different lengths of time because of time constraints associated with chemical immobilization. However, given that engorged adult female ticks are relatively large (approaching 1 cm³ when fully engorged) and easy to observe, we believe that even examinations of bears that were curtailed because of the recovery from immobilization provided a reasonable qualitative and quantitative assessment of the extent of parasitism. We stored engorged ticks in 95% ethanol and later identified them to species (Gregson 1956, Keirans and Litwak 1989, Keirans and Durden 1998). The same individual (H.S. Al-Warid) conducted all identification.

For each host, we quantified tick species richness (infracommunity richness; Bush et al. 1977), and for each tick species, the prevalence and intensity (the mean and median numbers of ticks among infected hosts; Bush et al. 1977). We calculated 95% confidence intervals (CI) of prevalence (Sterne’s exact method) and mean intensity (based on 2,000 bootstrap replications) using the software Quantitative Parasitology 3.0 (Reiczigel and Rózsa 2011). For each species of tick, and for all species of ticks combined, we also quantified the extent of aggregation based on variance-to-mean ratios (s²/m) and the corrected moment estimate of k (the aggregation parameter of the negative binomial distribution) from the negative binomial distribution values (Wilson et al. 2002) using Quantitative Parasitology 3.0. Given, however, that these absolute estimates of parasitism may be biased by a lack of complete examination of some hosts, we focused on comparing relative infrapopulation sizes of each species on each host by quantifying the proportion of each infracommunity represented by each infrapopulation. Doing so allowed us to address whether the general pattern of parasitism by the tick species was similar across hosts.

We used a Spearman rank correlation to test for an association between the number of ticks per host and the number of engorged ticks per host.

**Results**

We examined and collected ticks from 17 black bears (5 male, 12 female; 12 adult, 5 subadult). Examined bears were captured or obtained from Howell (n = 5), Douglas (n = 4), Ozark (n = 3), Shannon (n = 2), Wright (n = 2), and Oregon (n = 1) counties.

All examined bears were parasitized by ixodid ticks, and all hosts had engorged ticks. We counted 6,993 ticks overall (range = 30–1,120/bear), with a mean infracomunity size of 411.4 (95% CI = 274.6–595.8) ticks/host. We collected 967 engorged ticks, representing 13.8% of all ticks collected. Across all tick species and hosts, the mean number of engorged ticks was 56.9 (95% CI = 38.1–91.8; range = 5–230 engorged ticks/host). There was a correlation between the number of ticks per host and the number of engorged ticks per host (Spearman’s ρ = 0.801, 15 df, P < 0.001).

We identified 5 species of ticks (Table 1). Modal species infracommmunity richness was 3 (range = 1–5). *Amblyomma americanum* (lone star tick) was the most common tick species, was collected on all surveyed bears, and represented 58.2% of the total engorged ticks. *Dermacentor variabilis* (American dog tick) and *Ixodes scapularis* (blacklegged tick) were also common, whereas *A. maculatum* (Gulf Coast tick) and *D. albipictus* (winter tick) were less prominent, occurring on only 4 and 3 bears, respectively, and representing 2.4% and 4.7% of the total number of examined engorged ticks.
Table 1. Community of engorged Ixodid ticks collected from 17 American black bears during 2015 in southern Missouri, USA. For D. albipictus sample size was insufficient to estimate the corrected moment estimate (k).

<table>
<thead>
<tr>
<th>Species</th>
<th>Prevalence (%; 95% CI)</th>
<th>Mean intensity (95% CI)</th>
<th>Median intensity</th>
<th>Variance:Mean</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amblyomma americanum</td>
<td>100 (80–100)</td>
<td>33.7 (23.4–54.3)</td>
<td>34.0</td>
<td>31.56</td>
<td>1.607</td>
</tr>
<tr>
<td>Amblyomma maculatum</td>
<td>24 (8–49)</td>
<td>5.8 (2.0–9.8)</td>
<td>5.0</td>
<td>7.94</td>
<td>0.104</td>
</tr>
<tr>
<td>Dermacentor variabilis</td>
<td>71 (46–88)</td>
<td>22.3 (13.9–32.8)</td>
<td>18.5</td>
<td>21.08</td>
<td>0.395</td>
</tr>
<tr>
<td>Dermacentor albipictus</td>
<td>18 (5–42)</td>
<td>15.0 (2.0–24.3)</td>
<td>13.0</td>
<td>22.52</td>
<td>n/a</td>
</tr>
<tr>
<td>Ixodes scapularis</td>
<td>53 (29–75)</td>
<td>7.7 (4.7–12.0)</td>
<td>6.0</td>
<td>8.11</td>
<td>0.331</td>
</tr>
</tbody>
</table>

respectively. Representative voucher specimens of A. americanum and D. variabilis (but not the other taxa; see Discussion) were deposited in the University of Missouri’s Enns Entomology Museum.

For tick species with sufficient sample sizes, $k \leq 1.7$ indicated an aggregated distribution of ticks across examined bears, and for D. variabilis and I. scapularis, $k \leq 0.4$ indicated these species were highly aggregated on a few extensively parasitized hosts. The $s^2/m$ ratios provide similar indications of population aggregation, although these aggregation indices should be interpreted cautiously because of small sample sizes. Histograms for the 3 most common tick species demonstrate the extent of aggregation (Fig. 1): for A. americanum, D. variabilis, and I. scapularis, the 5 bears with the largest tick intensities supported 59%, 74%, and 82% of the entire engorged tick component population, respectively. Further, for A. americanum and D. variabilis, bears within the top 5 categorical histogram bins harbored 73% and 84% of the ticks, respectively (Fig. 1).

The relative abundance of the 2 most common tick species was similar across bears. For 16 of 17 bears, A. americanum was the most common species, with the exception occurring for one bear with a large ($n = 46$) D. variabilis infrapopulation. Dermacentor variabilis was the first or second most common species on 8 bears. Engorged I. scapularis occurred on more than half of examined bears, but the mean intensity was relatively low and the extent of aggregation was high ($k = 0.3$; Table 1). Engorged females of the other 2 tick species (D. albipictus and A. maculatum) occurred at lower prevalence, although when they occurred the mean intensity on parasitized hosts was nearly equal to that observed for I. scapularis, despite that latter occurring on half of examined bears.

Discussion

Each of the 5 tick species observed in this study are generalist taxa and have been previously reported on black bears elsewhere in their geographic range [Rogers 1975 Rogers and Rogers 1976 Manville 1978 Yabsley et al. 2009 Leydet and Liang 2013 Zolnik et al. 2015]. However, their relative abundance in these previous studies differs from that observed in Missouri because A. maculatum was more prevalent and A. americanum less prevalent in Louisiana, USA [Leydet and Liang 2013], and I. scapularis was more common (>40%) in Florida and Georgia, USA [Yabsley et al. 2009]. Comparisons of our findings with those of previous studies should be made with caution because these previous efforts did not emphasize engorged ticks and the goals and survey methodologies differed among studies, with most having a more general focus on pathogens associated with the ticks.

Most of the tick species we observed on black bears are relatively common in the Ozark Highlands region. For instance, A. americanum, I. scapularis, and D. variabilis have been reported from diverse hosts and habitat in Missouri [Roland et al. 1998 Kollars et al. 1997 2000a] by Steiert and Gifloy 2002 Bacon et al. 2003 Monello and Gompper 2007 Brown et al. 2011]. An important caveat, however, is that we did not place representative voucher specimens of all the species in a museum collection. As such, the presence and timing of these species on black bears in Missouri requires further confirmation. In contrast, the geographic distribution of A. maculatum extends northward only to the southern-most portion of Missouri [Estrada-Peña et al. 2005 CDC no date], where bears in our study were captured. The large home ranges and potential for long-distance movements of black bears and their expanding range in Missouri [Wilton et al. 2013 Hiller et al. 2015a] combined with the potential for A. maculatum to feed to repletion on black bears, suggests black bears could play a role in the northward range expansion of this tick species. The observation of D. albipictus on bears in Missouri is noteworthy because this tick has not been previously recorded from bears in the southeastern United States. However, it has been reported at low prevalence from black bears in the northern United States and Ontario,
A. americanum

D. variabilis

I. scapularis

Fig. 1. Histograms of the number of ticks collected per American black bear \((n = 17)\) during 2015 in Missouri, USA. For each species, bears with \(n = 0\) ticks are included. Histogram bin size is 10 for *Amblyomma americanum* and 5 for *Dermacentor variabilis* and *Ixodes scapularis*.

Canada (Rogers 1975, Addison et al. 1978, Manville 1978). *Dermacentor albipictus* has been reported from hunter-harvested (in the month of November) white-tailed deer (*Odocoileus virginianus*) from southeastern Missouri and central Illinois, USA (Kollars et al. 1997, Cortinas and Kitron 2006). In the Missouri study, the prevalence on deer was 0.0–5.6% across the 8 counties examined. With the exception of one county, this is less than the 95% CI for prevalence we estimated for black bears in our study, although sampling periods for deer and bear examinations differed.

The strong patterns of aggregation of individual tick species on particular hosts is commonly observed (Wilson et al. 2002). For instance, raccoons (*Procyon lotor*) examined in central Missouri had similar \((k = 0.6)\) patterns of parasitism by engorged *D. variabilis* (Monello and Gompper 2007). Such patterns are caused by variation in host susceptibility or host exposure to the parasite. However, to date, we are not aware of studies that have attempted to address the underlying causes of variation in the extent of individual-level parasitism by ticks (or other ectoparasites) in bears. Given the expansion of black bears in Missouri, and movements generally characterized by long distances, this recolonizing population may serve as an effective host to affect tick species distributions within Missouri.

Acknowledgments

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